**Thesis:** The use of rice residues as a thermo-chemical or bio-chemical energy source offers both environmental and economic benefits.

1) **Thermo-chemical process:** Thermo-chemical process can be classified into two categories (Lim et al., 2012): direct usage of biomass as fuel for combustion, and transforming biomass into other effective resources of green energy. Goyal, Seal, & Saxena (2008) discussed various thermo-chemical technologies, including direct combustion, gasification, and pyrolysis.

   a) **Direct Combustion:** Rice straw can either be utilized alone or blended with different biomass materials in direct combustion; boilers are used in combination with steam turbines to generate (cogeneration) electricity and heat simultaneously. Technology of utilizing rice husk to produce heat and electricity has been well studied.


   b) **Gasification:** Biomass is directly transformed to synthesis gas (syngas) in a gasifier under a measured amount of air, which can be used in internal combustion (IC) engine to produce heat, or in a cogeneration system to produce heat and electricity (Lim et al., 2010). The gasification route is preferred for low scale power generation as a small steam power plant is very inefficient and inconvenient to maintain due to the presence of a boiler. Apart from that, the gas produced from rice husk can be used in the existing diesel engine in a dual fuel operation.

   c) **Pyrolysis:** Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen, which occurs under pressure. Both rice husk and rice straw can be used to produce bio-oil via pyrolysis.

b. Ji-Lu (2007) figured out the efficient way of getting bio-oil from fast pyrolysis of rice husk and improvement of the pyrolysis system.

2) **Bio-chemical Process:** Biochemical transformation of biomass includes utilization of bacteria, microorganisms and enzymes to breakdown biomass into vaporous or liquid fuels like biogas or bioethanol. There are various bio-chemical processes and technologies to produce ethanol and hydrogen, such as anaerobic digestion (or biomethanation) and fermentation.

a) **Anaerobic Digestion:** During anaerobic digestion, bacteria break down organic material in the absence of air, yielding a biogas containing methane, which later used as fuel to generate heat and energy.

   a. Zhang and Zhang (1999) demonstrated the viability of using rice straw to yield biogas via a high-rate anaerobic digestion system, anaerobic-phased solids digester system.

   b. Lei, Chen, Zhang, & Sugiura (2010) found that Methane production from rice straw with acclimated anaerobic sludge will be more efficient if an adequate level of phosphate is added to the process..

b) **Ethanol Production from Fermentation:** Simultaneous saccharification and fermentation (SSF) or separate enzymatic hydrolysis and fermentation can be used to produce bio-ethanol from rice biomass such as rice straw and rice husk.

   a. Belal (2013) conducted a research on the factors that produce bio ethanol effectively via fermentation and showed that rice straw can potentially produce 205 billion liter bioethanol per year in the world (about 5% of total of consumption).
c) **Hydrogen Production from Fermentation:** Hydrogen production from rice straw or rice husk via fermentation can be very potential. However, more researches and technological developments are required to industrialize it.

**Environmental Benefits**

Producing bio energy from rice straw and rice husk is beneficial to environment.

1) **Carbon Dioxide reduction:** Producing electricity from rice husk can reduce the amount of Carbon dioxide (CO$_2$) in the atmosphere.
   
a. Chungsangunsit, Gheewala, and Patumsawad (2005) called to attention that the emission of CO$_2$ from combustion of rice husk are considered zero since they do not contribute to global warming.
   
b. Rice biomass can be utilized for lessening greenhouse effect since trees absorb CO$_2$, which is released when the biomass is combusted. Net amount of CO$_2$ added to the atmosphere during energy production from biomass over the entire life cycle is nearly zero.

2) **Alternative to Fossil Fuels:** Rice straw could be a source of alternative energy to substitute fossil energy for reducing greenhouse gas emissions.
   
a. Chungsangunsit et al. (2005) indicated that rice husk is a feasible feedstock for electricity production and performs better than fossil fuels.
   
b. Bioethanol produced from rice straw and biogas produced from rice husk can replace gasoline and coal. (Nguyen, Gheewala, & Garivait, 2007)

3) **Greenhouse Effect:** Bioethanol does not contribute to the greenhouse effect, because of its near zero production of CO$_2$ and is renewable and ecofriendly.
   
a. In Thailand, rice straw, used with current heat and power technologies, could replace fossil fuels to reduce sulphur dioxide and greenhouse gas emission. (Suramaythangkoor and Gheewala, 2010)
4) **Reduction of Air Pollution**: Producing green energy from rice straw and rice husk provides a solution to the past burning practice of rice straw disposal. These extensive activities cause discharge of pollutants such as carbon dioxide (CO2), carbon monoxide (CO), un-burnt carbon (with trace amount of methane), nitrogen oxides (NOx), and trace amount of Sulfur dioxide (SO2), which leads to cancer and asthma attack (Lim et al., 2010).

5) **Soil Problem Solution**: Rice straw has turned into a huge waste issue in Asia. In most agricultural systems, crop residues serve as a fertilizer for the next crop, but not in the intensive flooded rice systems that predominate in Asia since 2 or 3 crops are grown each year, with insufficient time for residues to break down and their incorporation would hinder soil preparation.
   
   a. It also causes crop diseases (Hrynchuk, 1998).

   b. Long term trials studied by Jun et al. (2007) showed that soil carbon levels can be maintained without needing to return straw to the soil.

**Economic Benefits**

Apart from being ecofriendly, green energy production utilizing rice residues also has some economic potential.

1) **Utilization of Husk in Rice Mill**: Husk production could be optimized by increasing the amount of processed paddy in mill. Rice husk is widely used to produce electricity in rice mills. When there is a surplus of rice husk, more than enough electricity is produced. Excess electricity can be sold to the grid to optimize revenue. Sookkumnerd, Ito, & Kito (2007) suggested that the combination of grid-connected generators into the husk-fueled stream engine influences positively on the financial performance of rice mills.
2) **Reduction of Fossil Fuel Import:** Rice producing countries need to import a large portion of fossil fuel every year for rice processing and to maintain other industrial activities. The rice husk is primarily utilized for steam producing in parboiling process and drying process of paddy. (Islam and Ahiduzzaman, 2013) Steam, a byproduct of power generation, can be used for paddy drying applications.

3) **Uses of Rice Residues Ash:** Selling rice husk and rice straw ash can be a decent source of income because of their economic potential. Due to the financial perspective of rice husk ash with high silica content, a few developers give priority to use rice husk as a single fuel (Lim et al., 2010). Rice husk ash, the byproduct of rice husk power plants, can be utilized in the cement and steel industries resulting in subsiding the need to import these materials.

4) **Energy Production and Export:** It can be a huge resource of income for the developing countries. Developing countries can initially utilize the energy to meet their national demand, and then surplus energies can be exported to developing countries.

**Issues and Possible Solutions Regarding Rice Residues**

1) **Straw Fuel Burning Difficulty:** Straw fuels have turned out to be extremely challenging to burn in most combustion furnaces due to its chemical components, especially those designed for power generation. The initial concern about the use of rice straw for power generation is fouling, slagging, and corrosion of the boiler due to alkaline and chlorine components in the ash.

   a. Pre-treatment of these resources can make them usable as fuel. (Lim et al., 2010) Anaerobic digestion can be a promising option for straw fuel burning problem. ("Rice Straw Project", n.d.)

2) **Rice Straw Collection Difficulty:** Rice straw bales are bulky and heavy in size.
a. In Thailand, 90% of the rice straw collected during the peak harvesting season between November and December are burned in the open fields (Tipayarom and Oanh, 2007).

i. To solve this problem, an efficient way of collection and distribution of straw should be initiated.

3) **Availability:** The availability of rice residue is only limited to harvest time. There are two ways to solve this problem. Storing surplus residues can be a good way to fight this problem. The other one is producing new breed of rice that can be harvested throughout the whole year.

4) **Low Feedstock Quality of Rice Straw:** The chemical composition of feedstock has a significant impact on the efficiency of cogeneration. The low feedstock quality of rice straw is primarily determined by high ash content (10–17%) as compared with wheat straw (around 3%) and also high silica content in ash. Rice straw as feedstock has low total alkali content, whereas wheat straw can typically have more than 25% alkali content in ash (McKendry, 2002). If straw is exposed to precipitation in the field, alkali and alkaline compounds are leached, the feedstock quality can be improved.

**CONCLUSION**
References


